3D reconstruction of lumbar vertebrae from computed tomography images

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INTRODUCTION:

Accurate 3D reconstruction of bony structures is essential for many clinical applications, such as evaluation of bone deformation, surgical planning and clinical follow-up of patients.

Computed tomography (CT) is a widely used medical imaging technique in clinical routine, especially for bones which provide high contrast. However accurate bone segmentation still remains challenging and often requires tedious manual processing, particularly for vertebrae. Some authors attempted to perform fully automatic multi-step labeling and segmentation of the whole spine (Klinder *et al.* 2009). However, such framework approach did not succeed in all cases, depending on the noise in images or presence of strong calcification.

The aim of this study was to perform a semi-automatic and robust 3D segmentation of lumbar vertebral body and pedicles from axial CT images. A validation study was conducted both on non-pathological vertebrae and on vertebrae with a vertebral body compression fracture.

METHODS:

Considering axial slices of the CT acquisition, digitally reconstructed radiographs (DRR) were computed from lateral and frontal view (de Bruin *et al.* 2008) and calibration parameters fixed by CT-scan parameters acquisition were defined. From these two DRR, an initialization of the lumbar vertebrae reconstruction was generated semi-automatically using a statistical parametric model based approach (Humbert *et al.* 2009). These initial reconstructions were automatically regionalized, so that pedicles and vertebral bodies can be easily isolated, together with anatomical landmarks identification.

For each region, profile intensity was determined for each vertex along its normal (Mastmeyer *et al.* 2006). Length profile was fixed to 7 mm on both sides of the normal considering that initial solution was relatively close to the true vertebral shape. Kmeans clustering algorithm with three classes was used to identify cortical bone, trabecular bone and soft tissue outside the vertebrae in the profile. External cortical threshold was set as 50% of the amplitude of the cortical/outside profile of vertebrae and defined the optimized position of the vertex. If the clustering algorithm could not assess a clear differentiation between the three classes for a vertex, no optimized position was defined for this vertex.

These optimized locations of vertex and their original position were used as control points to deform the complete model of the vertebra using the kriging dual algorithm (Trochu 1993). An iterative procedure was conducted reducing length profile until 1.5 mm. After each iteration, a smoothing of the vertebra was performed with a Laplacian filter as a regularization of the mesh.

CT acquisitions of lumbar spine of 6 patients with no vertebral fracture and no presence of instrumentation were used for validation. Pixel resolution varied from 0.26 to 0.34 mm², slice thickness was 1 mm with a gap of 0.5 mm. Ten CT acquisitions of patients with one vertebral body compression fracture (4 with osteoporotic fracture and 6 with traumatic fracture) were also used for validation; resolution varied from 0.27 to 0.66 mm², slice thickness ranged from 0.75 to 1.5 mm and gap from 0.3 to 1 mm.

Manual 3D reconstructions of these vertebrae, using AMIRA® software, were used as a reference. In order to estimate the confidence interval of such reconstructions, a reproducibility study was conducted on two fractured vertebrae. 2 operators achieved the manual segmentation at one occasion and a third operator performed the segmentation two times.

To evaluate the precision of the novel algorithm 3D vertebra reconstruction, point-to-surface distances between reconstruction and reference vertebra at the initialization step and after optimization were computed. The 95% confidence interval and maximum of the distance was quantified, considering pedicles and vertebral body areas.

RESULTS:

First, the 95% confidence interval for the manual reconstruction was found equal to 0.5 mm with a maximal difference of 3.1 mm between occasions or operators. Reconstruction time varied between 45 and 120 min.

For non-pathological vertebra and the novel algorithm, 95% CI was 0.6 mm (maximum 4.5 mm) for vertebral body and 0.75 mm (maximum 4.6 mm) for pedicles regions after optimization step. In case of patients with compression fracture, 2RMS was 1.1 mm in the pedicle region (maximum 2.3 mm) and was equal to 1.1 mm (maximum 3.8 mm) for vertebral body. Reconstruction time varied between 15 and 20 min, both for fractured and non fractured vertebrae, including the semi automatic initialization from DRR.

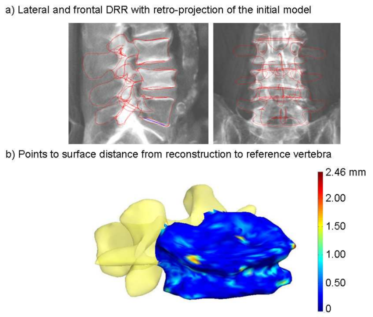

Figure 1: a) Frontal and lateral DRR with projection of the initial vertebra models. b) Point-to-surface distance (in mm) from the reconstruction to the reference vertebra.

DISCUSSION:

Quantification of the effect of vertebral augmentation is of paramount importance for objective evaluation of the augmentation techniques. Because of bias on 2D X-Rays, CT scan appears as particularly useful, but the main limitation is the time necessary for 3D reconstruction.

In this study, a novel algorithm based on a semi automatic initialization starting from DRR computed from CT images, followed by an optimization step appeared as efficient.

This approach was validated on non-pathological lumbar vertebrae and on vertebrae with compression fracture of the vertebral body. Such 3D reconstruction could be useful for clinical evaluation and surgical planning in the case of fractured vertebrae. Based on this reconstruction, quantitative fracture characterization will be the next step.

Further developments will be conducted to extend the optimization procedure to the posterior arch of the vertebra, taking into account of the adjacent bony structures, as articular facets for example.

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